Hydro-Thermal Vent Mapping with Multiple AUV's
AZORES-2001

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LONG TERM GOAL

The Naval Postgraduate School (NPS) and the Instituto Superior Tecnico, Lisbon (IST) have a long standing memorandum of agreement dating back to 1994 for the exchange of scientific ideas, visits of faculty and students, and to perform collaborative work. In the past we have collaborated on joint papers, the shared supervision of doctoral work, and a shared effort on the evaluation of AUV control system methodology. This is a NICOP project aimed at developing the technology of multiple cooperating AUV's in a shallow water vent-mapping mission. The missions to be conducted in the AZORES Islands will develop multi-vehicle cooperative strategies and control using radio and acoustic communications. Results of both sonar and video images will be obtained in which the Portuguese vehicle – INFANTE, and a surface catamaran (DELFIM) will perform broad area survey to identify vent clusters, while the NPS vehicle – ARIES, will be used to reacquire vent cluster locations, and perform local area searches with close in video data gathering.

OBJECTIVES

The major goals of the mission are to demonstrate the use of multiple AUVs to map the shallow water areas of the Azores. The objectives include using multiple cooperating AUVs and the evaluation of methodologies employed for multi-vehicle control, common control languages, and cooperative command and control. While there is a scientific need to study the vents with more detail than possible using divers and cameras, this also presents a parallel to the minefield reconnaissance and mapping problem in very shallow water - so necessary to the US Navy.

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14. ABSTRACT

The Naval Postgraduate School (NPS) and the Instituto Superior Tecnico, Lisbon (IST) have a long standing memorandum of agreement dating back to 1994 for the exchange of scientific ideas, visits of faculty and students, and to perform collaborative work. In the past we have collaborated on joint papers, the shared supervision of doctoral work, and a shared effort on the evaluation of AUV control system methodology. This is a NICOP project aimed at developing the technology of multiple cooperating AUV's in a shallow water vent-mapping mission. The missions to be conducted in the AZORES Islands will develop multi-vehicle cooperative strategies and control using radio and acoustic communications. Results of both sonar and video images will be obtained in which the Portuguese vehicle ??? INFANTE, and a surface catamaran (DELFIM) will perform broad area survey to identify vent clusters, while the NPS vehicle ??? ARIES, will be used to reacquire vent cluster locations, and perform local area searches with close in video data gathering.

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APPROACH

The IST has been conducting missions in the Azores using a surface catamaran vehicle (DELFIM) with plans to add an underwater vehicle (MARIUS). NPS will provide the cooperating underwater vehicle ARIES which has a video capability and an acoustic modem for underwater communications.

The approach for mapping these shallow water vent areas will be to employ an echo sounder on the Delfim to provide bathymetry and detect the presence and general location of clusters of vents. Delfim will communicate the cluster location data information by acoustic and radio modems to the NPS ARIES AUV. The ARIES will have the capability to reacquire the vent area using its DGPS / Doppler / IMU navigational suite, and to conduct a survey of the local area with a video camera. ARIES will provide geo-located video images of the vents, taken from a slow speed local search at constant altitude.

WORK COMPLETED

A joint exercise was conducted with IST, NPS, and the University of the Azores during the month of August near the Island of Faial, Azores. The detail objectives were:

- Demonstrate two vehicle underwater communications.
- Obtain video confirmation of shallow water hydro-thermal vent activity using video with location obtained from an independent source.

MAJOR RESULTS

- Navigational accuracy mostly errors < 5m obtained with GPS popup.
- Video acquisition obtained of vent area given position from an independent source. Vent bubbles were found.
- Acoustic communications between Delfim and ARIES with FAU modem where each vehicle was operated under autonomous control.
- All commands were received successfully and acted upon with no retransmits. The commands were sent from the support ship to the Delfim and then to ARIES. Ranges up to 700m with 2 vehicles underway.

For this mission, a pair of acoustic modems were installed on the ARIES and on the IST Defim autonomous surface craft as shown in Figure 1. Two lap top computers were used on the research vessel ARQUIPELAGO and are referred to as the base station systems. One laptop is used for command and control directly to the ARIES controlling computer through a radio link while the vehicle is surfaced. The second lap top is a two part link using both radio and acoustic modem communications. Radio communications are used from the ARQUIPELAGO surface ship to the Delfim, at which point the data is sent to an acoustic modem mounted below the craft and allows communications with the ARIES while it is submerged.

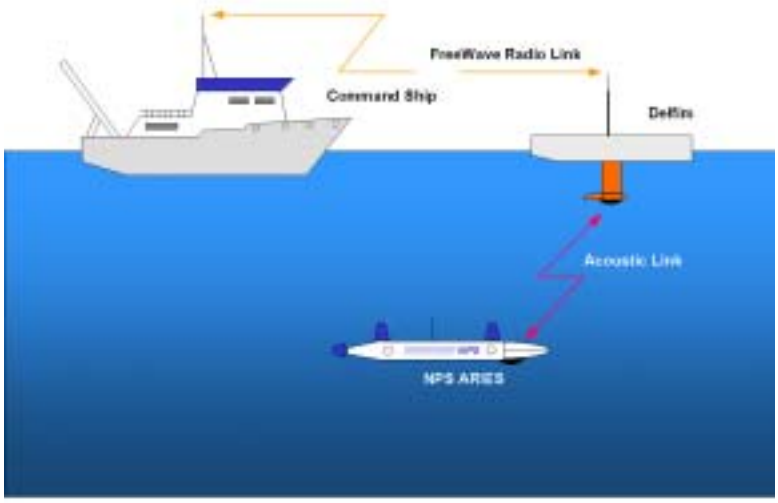

Figure 1. Command ship to ARIES via Delfim communications system.

Software integration into ARIES

The current configuration of the acoustic modem allows sending character strings up to 256 characters in length per transmit. For reasons of future compatibility across different systems, NMEA style ASCII strings are used as a standard format for the messages defined. The general form of all messages sent or received from the modem are of the form:

HEADER,COMMAND,PARAM1,PARAM2,…,PARAMn

Where

HEADER is either of the following:

- $FAUMS A set command type.
- $FAUMQ A query command type.
- $FAUMR A reply command type.

COMMAND is a keyword that determines the action to be taken and has a defined number of parameters given by PARAM1,PARAM2,…,PARAMn. Sufficient checking is performed so that if invalid or incorrect parameters are sent, no action will be taken and a parsing error will be returned. An overview of all valid message strings are given in Tables 1 and 2.

Table 1. Set Strings Available to Send to the Vehicle from the Base Station Acoustic Modem

"Set" String	Definition
$FAUMS,ABORT	Abort Mission and Surface.
$FAUMS,DEPTH,*Depth com*	Set Depth Command (meters).
$FAUMS,ALTIT,*Alt com*	Set Altitude Command (meters).
$FAUMS,CMODE,*Mode*	Set Control Mode, *Mode = 0* or *1*, *0* = Depth Control, *1* = Altitude Control.
$FAUMS,GOTOL,*Latitude,Sector, Longitude,Sector,LoitTime,TimeOut*	GoTo WayPoint and Loiter.

Where

Latitude = Latitude coordinate in degrees/minutes/fraction of minutes.
Sector = *N* or *S* for North or South.
Longitude = Longitude coordinate in degrees/minutes/fraction of minutes.
Sector = *E or W* for East or West
LoitTime = Duration of maneuver at loiter point.
TimeOut = Overall timeout for loiter maneuver. (>*LoitTime,* Abort if exceeded).
Mode = Vertical plane control mode. , 0 = Depth control, 1 = Altitude control.
Depth_com = Depth set point in meters.
Alt_com = Altitude set point in meters.

Table 2. Query Strings Available to Send to the Vehicle from the Base Station Acoustic Modem

"Query" to Vehicle	Definition	Response from Vehicle
$FAUMQ,POSIT	Return Current Position/Orientation Info.	$FAUMR,POSIT,*Latitude,Sector,Longitude,Sector ,X,Y,Heading,Depth,Altitude*
$FAUMQ,WAYPT	Return Current Way Point Info.	$FAUMR,WAYPT, *WayPindex*
$FAUMQ,CMODE	Return Current Control Mode and Set Point Value.	$FAUMR,CMODE, *Mode,Com Mode = 0* or *1, Com = Depth_com* or *Alt_com* Depending on the Control Mode, *Mode*.

Set commands are used to change or override current mission parameters in the ARIES, while query commands are used obtain information about the current state of the vehicle. All query commands receive a response containing the data requested.

At the present time, all vehicle behaviors are determined by a pre-programmed mission script file that is parsed by the ARIES controlling computer. The file contains a sequential list of commands that the vehicle is to follow during a mission. Two modes are available for control in the vertical plane, denoted depth or altitude control. Under depth control, the vehicle flies below the surface at a depth defined by a set point *Depth_com*. Using alititude control, the vehicle is commanded to fly above the bottom at an altitude defined by *Alt_com.* Either mode may be used while using cross track error control for horizontal motion control. With cross track error control, a series of predefined way points

are used for the vehicle to follow in sequence. The acoustic modem enables certain preset parameters to be changed while the vehicle is underway.

Referring to Table 1, the first and simplest of the set commands is to issue an immediate mission abort which will cause the vehicle to surface and terminate the current mission. The next set of commands allows the current depth or altitude set points to changed along with the control mode. The last set command is the most complex. GOTOL (Go to loiter point) causes the vehicle to suspend navigating to the current active way point and maneuver to a way point defined by *Latitude*, *Sector*, *Longitude*, *Sector*. Once the vehicle has reached the loiter way point, it executes a predefined search pattern around the area for a duration of *LoitTime* seconds. The parameter *TimeOut* is an overall safety timeout for the maneuver.

Table 2 outlines the available query commands used to retrieve information from the ARIES. The first query returns position information and includes the current estimate of the global position, and the position, *X*, *Y* of the vehicle relative to a predefined reference point. Vehicle depth, altitude, and heading are also transmitted. The second query returns the index number of the current way point to be achieved. The last command returns the control mode either depth or altitude along with the current set point value.

Within the ARIES control computer, a separate process is used to read and write to the acoustic modem. The modem process communicates with the main control program (execution process) through shared memory as shown in Figure 2. When a set message is sent from the base station, the string is read by the modem process, parsed, and the appropriate variables are set and written to shared memory. The execution process reads the modem shared memory and takes the appropriate action. The execution process updates a shared memory segment at 8 Hz with the current state information. Therefore, when a query command is received, all state information is available to the modem process without directly interacting with the execution program.

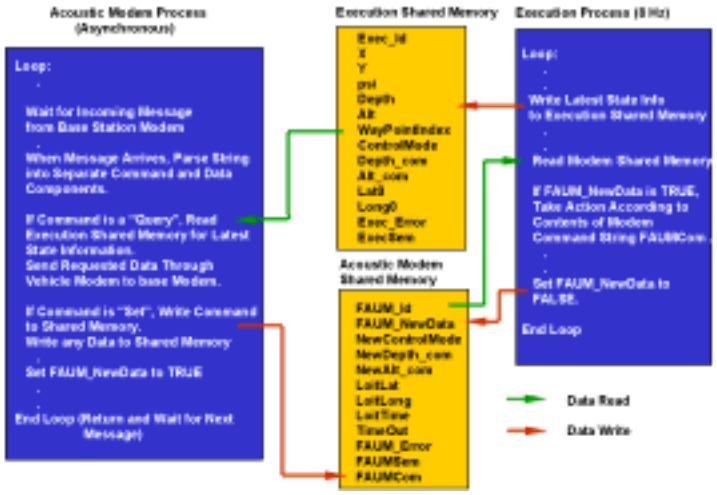

Figure 2. Acoustic modem and execution process communications method.

Table 3. Activities conducted by day are listed in the table below

Date	Activity
Monday, August 6	Unpack ARIES.
Tuesday August 7	Partial Re-Assembly of ARIES.
Wednesday August 8	System Connections and Testing.
Thursday August 9	Acoustic Modem Software Integration and Testing.
Friday August 10	Deployment of ARIES to ARQUIPELAGO Modem test and evaluation in Harbor Ballast tests in Harbor. Transit to Site, Mission 0.
Saturday August 11	Transit to Site. Navigation Tests of ARIES at Site, Development of New Deviation Table. Mission 1, 2, 3 – Navigation.
Sunday August 12	Missions 4,5,6 – Video. Missions 7,8,9 – Communications.
Monday August 13	Off load ARIES
Tuesday August 14	Pack up ARIES for Transportation.
Wednesday August 15	Pack up ARIES for Transportation.

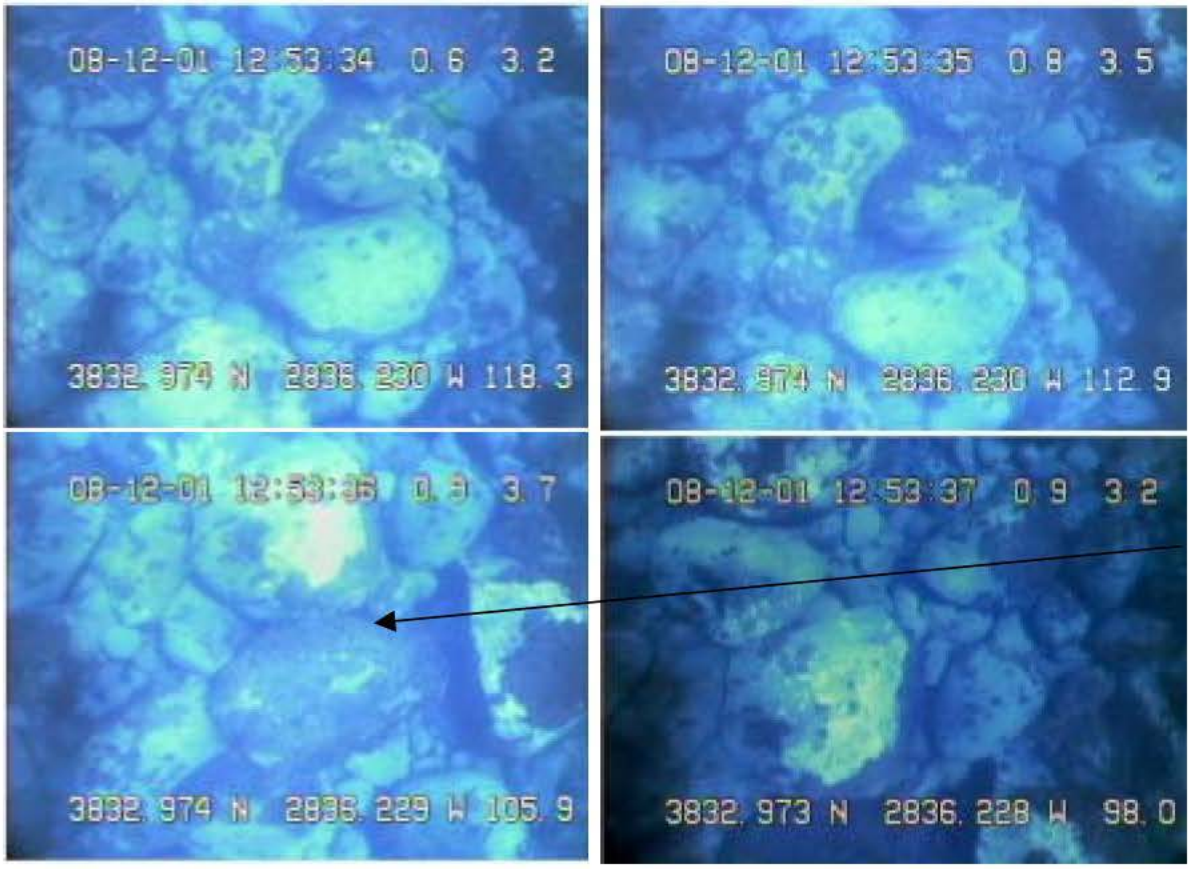

Figure 3. A sequence of frames from the video capture at 34,35,36,37, seconds that show on close up bubbles from the vent. The bubble stream is not constant and intense.

MPEG SNIPPETS OF SEGMENT AROUND VENT ACTIVITY

A short MPEG movie of the bubble sequence is found at
http://www.cs.nps.navy.mil/research/auv/images/azores01/BUBBLE2.AVI
This will require at least WIN 98, Windows Media Player, and QuickTime viewer.

REFERENCES

Healey, A. J., Marco, D. B., Pascoal, A. M., Santos, R.,et. al “Hydro-Thermal Vent Mapping with Multiple AUV's: AZORES-2001”, NPS Report # NPS-ME-01-007.